JOHN TYNDALL (1820–1893)[1]

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JOHN TYNDALL, British philosopher and physicist, was a most genial and interesting personality. In him a noble and generous nature was combined with a resolute will and lofty principles. He had a fine regard for the rights and feelings of others, and most of his controversies were in defense of truth and justice.

The great ideas of the conservation of energy and the mechanical equivalent of heat were novelties in his time, and his clear thinking and exposition did much to interpret the full significance of these laws. By the publication of his lectures in a style both clear and interesting, and expressed in non-technical language, he reached a large audience, and did more than any other person to secure the wide diffusion of these all-pervading truths that lie at the foundation of physical science.

In the Royal Society's catalogue of scientific papers 145 titles appear under Tyndall's name, and his more extensive writings comprise no less than 16 separate volumes. The complete story of a life so full can not be given in a single evening, and the mere reading of the titles of his many papers would occupy more time than is now allotted to me. But if we can catch a glimpse of his spirit, and gather a bit of inspiration from the enthusiasm with which he worked, this half hour will not be spent in vain.

John Tyndall was born near Carlow, in the southeastern part of Ireland, on the second of August, 1820. Originally of English descent, the Tyndalls crossed to Ireland in the seventeenth century. The elder John Tyndall, although poor, was a man of more than ordinary intellect, and he gave his son a good education in English and mathematics.

To a large extent, Tyndall was a self-made man. His mathematical training enabled him to enter the ordnance survey of Ireland at the age of nineteen, and because of his skill in drawing he was later selected for the English survey. For three years he was a civil engineer at Manchester, and during this

[1] An address delivered before the Research Club of the University of Michigan at a meeting commemorating the centenaries of John Tyndall and Herbert Spencer, 21 April, 1920.

time he spent much time in reading and in private study. It was partly through the reading of Carlyle that he was led to abandon the brilliant possibilities then open to a civil engineer, and devote his life to scientific study.

For some time he was connected with Queenwood College, in Hampshire County, where one of his duties was the instruction of a class in mathematics. His mind was ever on the alert to observe the natural phenomena of daily life, and his teaching was no mere following of text-book routine. It was his custom to give the boys their choice of following Euclid or trying problems of their own devising. The book was never chosen. Their diagrams were scratched on the walls and cut in the beams of the playground, thus showing the lively interest they took in the subject. They found it pleasant to prove by mathematics, and then verify by experiment, that the angular velocity of a reflected beam of light is twice that of the mirror from which it is reflected. And they were startled by the inference that if the earth turned seventeen times its actual speed all things at the equator would lose their weight and have the same tendency to fall upwards as downwards. The days spent with these boys made a deep impression upon Tyndall, and he looked forward to that future day when he might push these subjects a little further and add his own victories to the conquests already won.

The autumn of 1848 found him at Marburg, where, after two years of work, he received the degree of doctor of philosophy. His reputation as an investigator was established by the publication of his work on the magnetic properties of crystals, and the relation of magnetism and diamagnetism to molecular structure. The action of the atoms and molecules held an irresistible attraction for him and every investigation was conducted with molecular arrangement in mind. He was not satisfied with a few typical examples, but he examined nearly a hundred natural crystals and the entire collection of artificial crystals in the laboratory of Professor Bunsen. The subject was studied from every side until he had obtained a clear conception of all the conditions involved, and was able to formulate the general law.

Faraday had just published his researches on the behavior of crystals in taking a definite position when suspended between the poles of a strong magnet. "This force," he says, "appears to me to be very strange and striking in its character . . . for there is neither attraction nor repulsion."

It required long and patient effort to bring under the dominion of elementary principles the vast mass of facts which

experiments had brought to light, but the more he worked at the subject the more clearly did it appear to Tyndall that the action of crystals in the magnetic field was due, not to some new and unknown force, but to the modification of the known forces of magnetism and diamagnetism by the crystalline structure. It *was* true that the forces were neither attraction nor repulsion, taken singly, but it was *both,* thus producing a torque which turned the crystal into a determined position. The painstaking observations and the simply stated conclusion showed the qualities for which his work was ever distinguished.

Shortly after his return from Marburg he was appointed professor of physics in the Royal Institution, where Faraday was then director. Seldom have two men worked together so harmoniously as did Tyndall and Faraday during the years that followed. Their relationship from first to last was like that of father and son, and when Faraday died, fourteen years later, Tyndall succeeded him as director of the Royal Institution.

It was at this time also that he became acquainted with Spencer, who was about his own age, and with Huxley who was five years younger. This was the beginning of the most intimate of friendships. On all sorts of minor topics they were liable to differ in opinion, and they never hesitated to criticize each other; but the fundamental harmony between them was profound, for each cared immeasurably more for truth than for anything else. It was no small factor in his life for Tyndall to enjoy the friendship of these two men.

Not all of the investigations of Tyndall were carried out in the laboratory, for he was always awake to the events of daily experience. Even the "spirits" did not escape his observation, and it is especially interesting at this time to read of Tyndall's experience in this field.

The spirits themselves named the time and place of meeting, which proved to be a dinner at a private residence near London. The medium—a delicate looking young lady—was seated next to Tyndall. He records a bit of the conversation. He asked the young lady if she could see the curious things he had heard about—the light emitted by crystals, for example. "Oh, yes," she replied, "but I see light around all bodies."

T. "Even in perfect darkness?"

Med. "Yes; I see luminous atmospheres round all people. The atmosphere which surrounds Mr. C. would fill this room with light."

T. "You are aware of the effects ascribed to magnets?"

Med. "Yes; but a magnet makes me terribly ill."

T. "Am I to understand that, if this room were perfectly dark, you could tell whether it contained a magnet, without being informed of the fact?"

Med. "I should know of its presence on entering the room."

T. "How?"

Med. "I should be rendered instantly ill."

T. "How do you feel to-day?"

Med. "Particularly well; I have not been so well for months."

All the while there was in Tyndall's pocket, within six inches of her, a magnet; but he felt that nothing would be gained by showing it.

On the whole the evening was a dull one, but towards the end the spirits were asked to spell the name by which Tyndall was known in the spirit world. As the alphabet was slowly repeated a knock was heard when the letter P was reached. Beginning again, the letter O was knocked down. The next letter was E.

The knocks seemed to come from under the table, and Tyndall asked permission to go underneath to assure himself of the origin of the sounds. He remained under that table for a quarter of an hour, and was sure that no sound could be produced without his being able to locate its source. The spirits were urged and entreated to finish the word, but they had become dumb, and could spell no more. Tyndall then returned to his chair, but not without a feeling of despair regarding the prospects of humanity, never before experienced.

The spirits, however, resumed their spelling, and dubbed him, "Poet of Science." More than once after this he accepted invitations to be with the spirits. His comment is, "they do not improve on acquaintance. Surely no baser delusion ever obtained dominance over the weak mind of man."

In the autumn of 1854 Tyndall attended a meeting of the British Association at Liverpool, and at its close he took the opportunity to visit North Wales, where he saw the slate quarries. It interested him to see how readily the rock split open in parallel planes, like wood before an axe. The explanation that these were the layers in which the material was deposited did not satisfy him. Consultation with geologists showed him that the planes of cleavage were not those of stratification, and further investigation on numerous substances convinced him that the cleavage was caused by the effects of pressure.

Two years later these phenomena were made the subject of a lecture at the Royal Institution. His friend Huxley was

present, and suggested that this aspect of slaty cleavage might have some bearing on the laminated structure of glacier ice. They were both going to Switzerland that summer, and they arranged a joint excursion over some of the famous glaciers, where they could observe together the veined structure of the ice.

No man knows, when he commences the examination of a physical problem, where it will lead him. For Tyndall this was the beginning of many visits to the Alps, where he continued the study of glaciers for many summers. He satisfied himself that the veined structure was due to pressure, but he was especially interested in learning how a crystalline solid like ice could flow like a liquid. He pointed out the inadequacy of earlier theories, and showed by experimental demonstration that the flow was due to continued minute fracture and subsequent refreezing of the ice.

But once in Switzerland, the fascination of the mountains claimed him, and he became an Alpine enthusiast. Summer after summer he returned to conquer some untrodden Alp, or continue an unfinished investigation. The ascent of Mont Blanc was not complete without planting thermometers at several stations to record the cold of winter while he was absent. Nor was science alone to benefit from these excursions. The volumes that record his experiences are gems of literature, pervaded from cover to cover with the vigor and freshness of the Alpine air.

Tyndall always considered original investigation to be the great object of his life, and his most extensive researches are those in the domain of radiant heat. These experiments were stimulated by the conviction that not only the physical, but also the molecular, condition of bodies probably played a very important part in the phenomena of the radiation and absorption of heat. He wanted to show the physical significance of an atomic theory which had been founded on purely chemical considerations, and this object was continually kept in mind. Radiant heat was used as an instrument to explore molecular condition, and to bring clearly into view the astonishing change in physical properties when the atoms of simple gases unite to form more complex combinations.

As new advance often awaits the production of new instruments, so Tyndall's first requirement was a galvanometer of increased sensitiveness. Having made this galvanometer, and also a sensitive thermo-pile, he proceeded to examine the absorption of radiant heat by various gases. The gas to be examined

was placed in a long tube, closed at each end with windows of rock salt. The source of heat was a copper cube filled with hot water. The heat radiating from this copper box passed through the gas in the tube and fell upon the thermopile placed just outside the farther window. The other face of the thermo-pile was warmed from a second source, similar to the first. When the tube was empty, the galvanometer pointed to zero. When the tube was filled with gas, if the molecules possessed any power of intercepting the heat waves, that side of the thermo-pile would receive less heat, and the galvanometer would show a deflection corresponding to the amount of heat thus absorbed by the gas.

Examined in this manner, dry air, oxygen, nitrogen, and hydrogen showed a very slight absorption of the radiant heat. But when in chemical combination, the astonishing fact appeared that carbon dioxide absorbed nearly 1,000 times as much as dry air. Nitric oxide absorbed 1,600 times as much as either nitrogen or oxygen. And ammonia absorbed 5,500 times as much as either of its constituents. To make sure that these results were real, and that errors in the method of observation, or impurities in the gases used, did not mask the true effects, required some thousands of experiments. Observations were repeated again and again, and under various conditions, until he was thoroughly familiar with all the factors that could affect the result. And conclusions were not published until the experiments had convinced him that they were correct.

The case of aqueous vapor in the air proved so interesting and important that a special series of experiments was made upon it. Not only was the air of London examined, but to avoid possible errors due to the effect of local impurities, air was brought from the country and from the seashore. This air, containing the normal amount of aqueous vapor, absorbed 70 times as much heat as air from which the moisture had been removed.

The importance of these results are manifest when they are stated in a different way. It appears from this that the aqueous vapor which exists within ten feet of the earth's surface on a day of moderate humidity is sufficient to absorb 10 per cent. of the entire terrestrial radiation, a considerable portion of which is thus returned to the earth. He thus explained the burning heat by day, followed by the enormous chilling at night, in those places that are not protected by a blanket of moist air. In a general way, this has been referred to the purity of the air, but this purity consists in the absence of the transparent

vapor, rather than that of smoke or other visible constituent.

Thus a comparatively slight change in the variable constituents of the atmosphere, by permitting free access of solar heat to the earth and checking the outflow of terrestrial heat into space, might produce changes of climate as great as those which the discoveries of geology reveal.

An extension of this inquiry led him to investigate the absorption of heat by various liquids and their vapors. The behavior of these vapors placed them in a definite order of relative absorption. For heat of the same quality, and using equivalent amounts of the different liquids, he proved that the liquids occupied the same order as their vapors. This led him to the conclusion that the act of absorption is molecular, and that the molecule maintains its power as an absorber and radiator in spite of its change from liquid to vapor. Later he considered this action as due, in large part, to the atoms composing the molecule, rather than its being solely a property of the molecule as a whole.

In another series of experiments the source of radiant heat was a flame of burning gas. The radiation from the hydrogen flame possessed a peculiar interest, for he thought it likely that the resonance between its periods of vibration and those of the cool aqueous vapor of the air might be such as to cause the atmospheric vapor to exert a special absorbent power.

His surmise in this respect was justified, for he found that 20 per cent. of the total radiation from the hydrogen flame was absorbed by 50 inches of *undried* air, whereas only about 6 per cent. of the radiation from a hot platinum spiral was thus absorbed. Nor was this resonance confined to aqueous vapor. The dried air, which was now transparent to the hydrogen flame, was able to absorb 14 per cent. of the heat from a flame of carbon monoxide. Air from the lungs, with the moisture removed, was able to intercept 50 per cent. of the entire radiation from the carbon monoxide flame.

As a result of these investigations, carried out with extreme care and in great detail, he showed the very intimate relation between the absorption of heat and the molecular condition of the absorbing body.

In connection with these experiments, he also showed that those bodies that were the most efficient absorbers of radiant heat were likewise the best radiators of that same heat.

But while we are greatly indebted to Tyndall for the new knowledge which he discovered in the domains of heat and other branches of physics, his name will continue to be loved and re-

membered even more for the interesting lectures in which his methods of research were explained to public audiences, and the fundamental principles of science made clear to them.

It must have been a delight to listen to him. He was famed for the charm and animation of his language, for lucidity of exposition, and singular skill in devising and conducting experimental illustrations. Both he and his younger friend Huxley were popular with the London audiences, but they were very different. Huxley convinced his audience and compelled their assent; Tyndall carried them with him. They could not help agreeing with Huxley even if they did not wish to do so; they wished to agree with Tyndall if they could. It was the aim of Tyndall to rise to the level of his subject from a basis so elementary that every one in his audience could comprehend it, and then to lead them on by experimental demonstrations to a more complete understanding of the truths of Nature.

In the autumn of 1872 he came to America, where, in several of the eastern cities, he delivered a series of lectures on "Light." His success as a lecturer was complete. At first he was somewhat in doubt regarding the intellectual level that might be expected of the audiences, but he received early warning to talk the same as he would at the Royal Institution. One who heard him says: "It was a rare treat to hear him lecture. His illustrative experiments were beautifully done, his speech was easy and eloquent, and his manner, so frank and earnest and kindly, was extremely winning." His reception throughout was that of a friend by friends; and he looked back upon his visit as a memory without a single stain of unpleasantness.

The noble nature of the man and his unselfish devotion to the science he loved is shown by his attitude towards financial reward. This lecture season brought him about $13,000 over his actual expenses, but he would not take a cent of it. He left it all in the hands of trustees as a fund for the benefit of science in America. At the present time this fund is in the form of three graduate fellowships in physics—at Harvard, Columbia, and the University of Pennsylvania. It is of interest to recall that one of our own men has recently enjoyed one of these fellowships.

Tyndall, like most of his friends, was a reverent agnostic. He did not believe that the ultimate truths of the universe could be expressed in words, or that our limited and finite intelligence could as yet comprehend them. His writings, however, contain many phrases which show that he was familiar with the books of Holy Scripture. And often, after a Sunday evening tea, he would join his friends in the singing of psalm tunes.

On the question of miracles, he did not deny their possibility, but he compares, for example, the horse power involved in stopping the sun and moon (or was it merely the rotation of the earth?) with the feeble efforts expended by Joshua and his men in pursuing the five kings of the Amorites. And with characteristic consideration for the author, he points out that for him the sun was only a moving lantern, whose motion could be varied at the will of the appropriate authority.

His views on the great question of the relation between science and religion were expressed in his presidential address before the British Association at Belfast. In this address he outlined the fortunes of science from the times of the Greeks and the Moors, and depicted the struggle of truth against ignorance and superstition. Tracing back the theory of Darwin to the beginnings of life, he saw only the unbroken workings of Nature, extending beyond the range of experimental evidence, and this led him to the conclusion that the possibility of life must have existed in the atoms of the nebulæ.

He strongly maintained the claims of science to discuss such questions fully and freely in all their bearings, whatever the results might be. Such an address, delivered at the present time, would cause scarcely a ripple of dissent, but at that time it brought down on his head the severe criticism of those who differed from him, and a three days fast was proclaimed to keep infidelity out of Ireland.

An accident in the Alps may have been the cause that turned his mind to investigations in another direction. Having taken a shower bath under the cascade of an Alpine stream, he was returning for his clothes when he slipped and the sharp granite pierced his shin. Dipping his handkerchief in the clear water of the stream he bound up the wound and limped to his hut, where he lay quietly for several days. There was no pain, and upon removing the bandage the wound was found to be clean and uninflamed. But it soon became inflamed, and he had to be carried on men's shoulders to Geneva, where for six weeks he was confined to his bed.

About this time there was considerable dissension regarding the spontaneous generation of life, and Tyndall could not let such a question of fact pass by without adding his own clear logic to the discussion.

In the investigations on radiant heat it had been necessary to use air from which all traces of floating dust had been removed. A sensitive test of such purity was found in a concentrated beam of intense light, which rendered visible particles smaller than any microscope could detect.

Convinced that the reported cases of spontaneous generation of life were due to infection from the air, he wanted to try the effect of this optically pure air. Fifty wooden chambers were built, with windows on each side for the passage of a strong beam of light. When this showed that the air within was free from floating particles, various infusions of meat and vegetable were introduced in open test tubes and properly sterilized. There was no shade of uncertainty in any of the results. All of the infusions remained pure and sweet, although some of them remained freely exposed to the air in the chamber for over a year. Out of a total of 500 chances, there was no appearance of spontaneous generation. But when the air from the laboratory was allowed to enter the chambers, the infusions swarmed with life in two or three days.

Believing in the germ theory, and realizing that in certain stages of development the germs are more readily destroyed by heat, he devised the method of sterilization by repeated heating. In this method the infusion is brought to the boiling point, and then set aside for ten or twelve hours, after which it is brought to the boiling point again. Successive heatings in this manner destroyed the most resistant germs, three minutes of repeated boiling being more effective than 300 minutes of continuous heating.

In recognition of these researches he was given the degree of M.D. by the medical faculty of Tübingen.

At the age of 55 he married the charming and accomplished daughter of Lord Hamilton, whom he met during one of his Alpine excursions. They were companions in all things, living in his rooms at the Royal Institution, and spending their summers among his old haunts in the Alps. But his later years were marred by ill health and sleeplessness, and by accident, one evening in 1893 he took an overdose of chloral, from the effects of which he never awoke.

No other man had done more by research, lectures and writings, to discover and disseminate a sound knowledge of natural phenomena. And because there was no sacrifice of truth for popularity, the books he wrote half a century ago are classics at the present time.